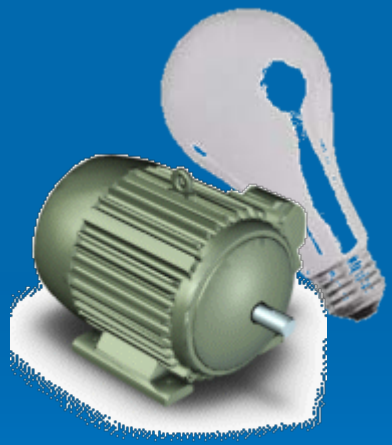
ASSOCIATION OF ENERGY ENGINEERS
NORTHERN OHIO CHAPTER

APRIL 21, 2005

Two Types of Electrical Loads

- Linear

INCANDESCENT LIGHTING



INDUCTION MOTORS

- Non-Linear

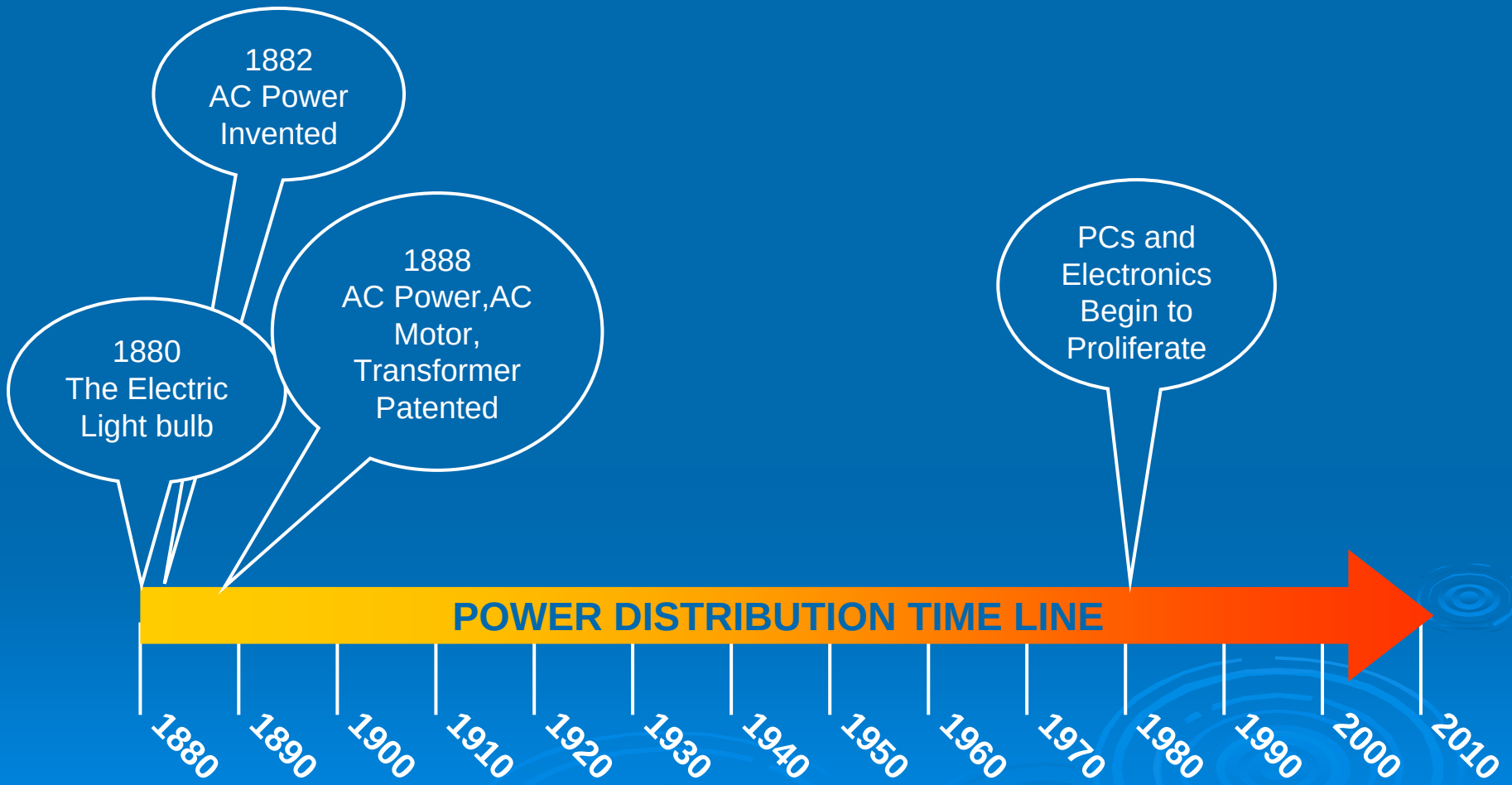
COMPUTERS

VARIABLE FREQUENCY DRIVES

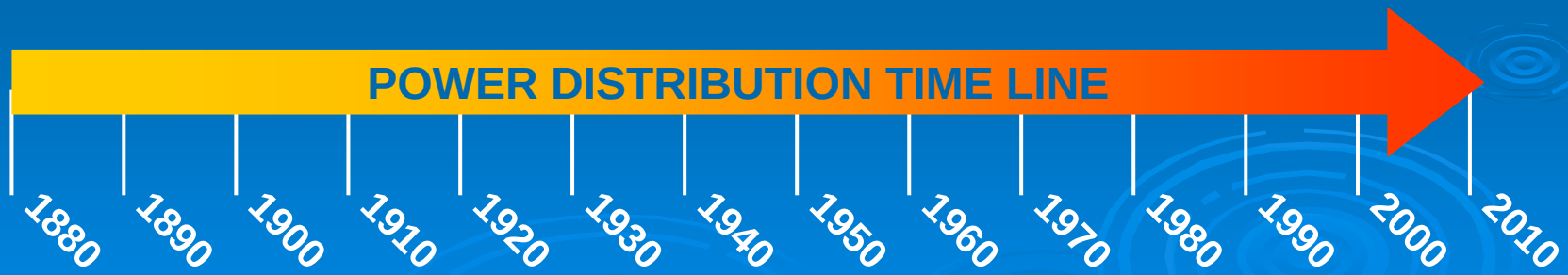
ELECTRONIC BALLASTS

FLUORESCENT & HID LIGHTING

Milestones in the History of AC Power Distribution and Power Quality

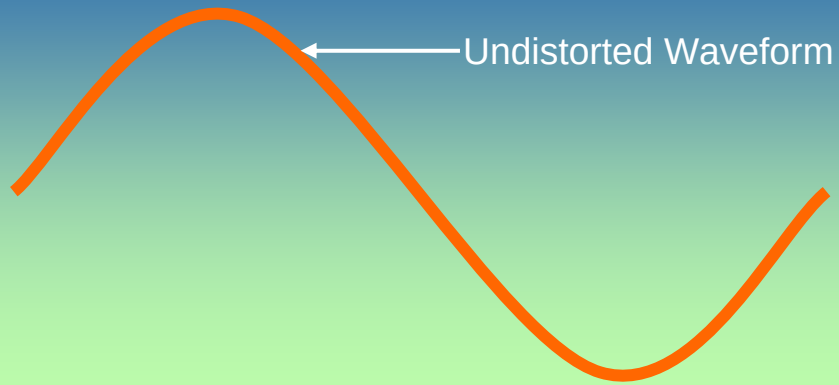


The Mix of Linear to Non-Linear Loads Shifted Suddenly After 1980

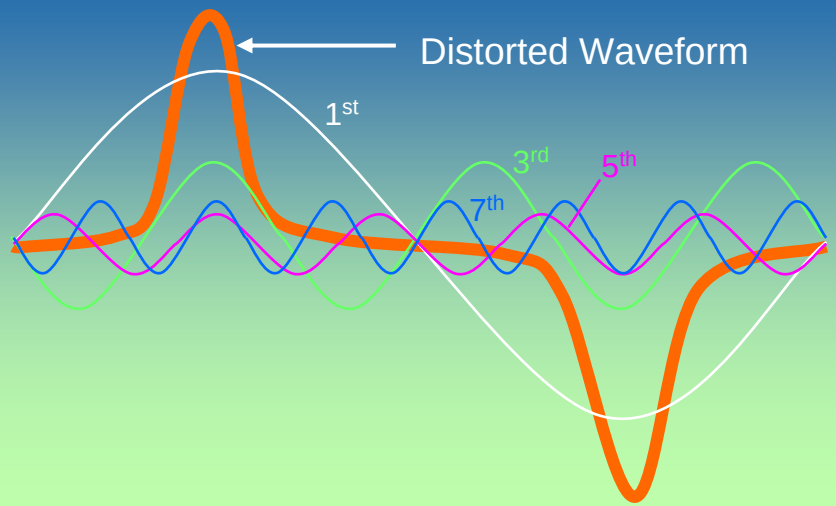


Engineers Describe Electrical Distortion in Terms of Harmonic Content

- An undistorted power waveform is a pure sine wave with no harmonics
- The power waveform has a frequency of 60 Hertz

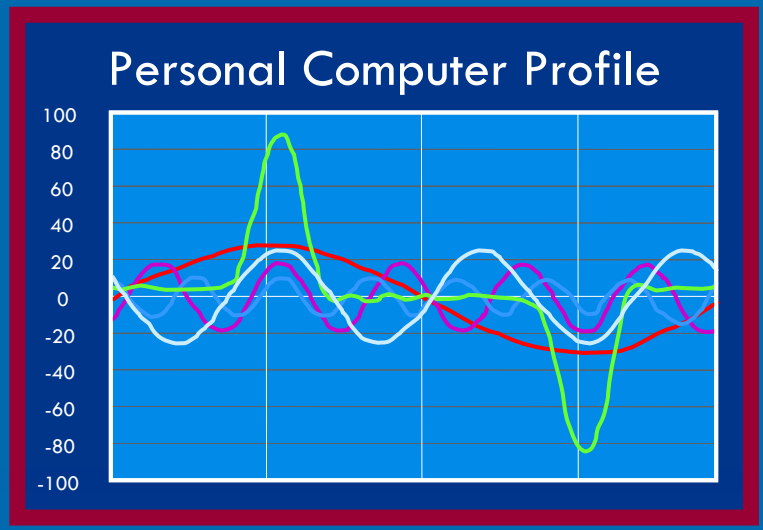


- A distorted waveform contains many related waveforms called harmonics
- They usually include the 3rd, 5th and 7th multiples of 60 Hertz
- Harmonics waste energy



What are Harmonics

Harmonics are multiples of the fundamental frequency that when added to the fundamental component regenerate the original waveform



Computer's Pulse (in green) can be represented by the sum of fundamental (60Hz), 3rd, 5th, 7th, … harmonics.

Fundamental Frequency = 60 hz

Typical Non-Linear frequencies:

3 x 60 = 180HZ

5 x 60 = 300HZ

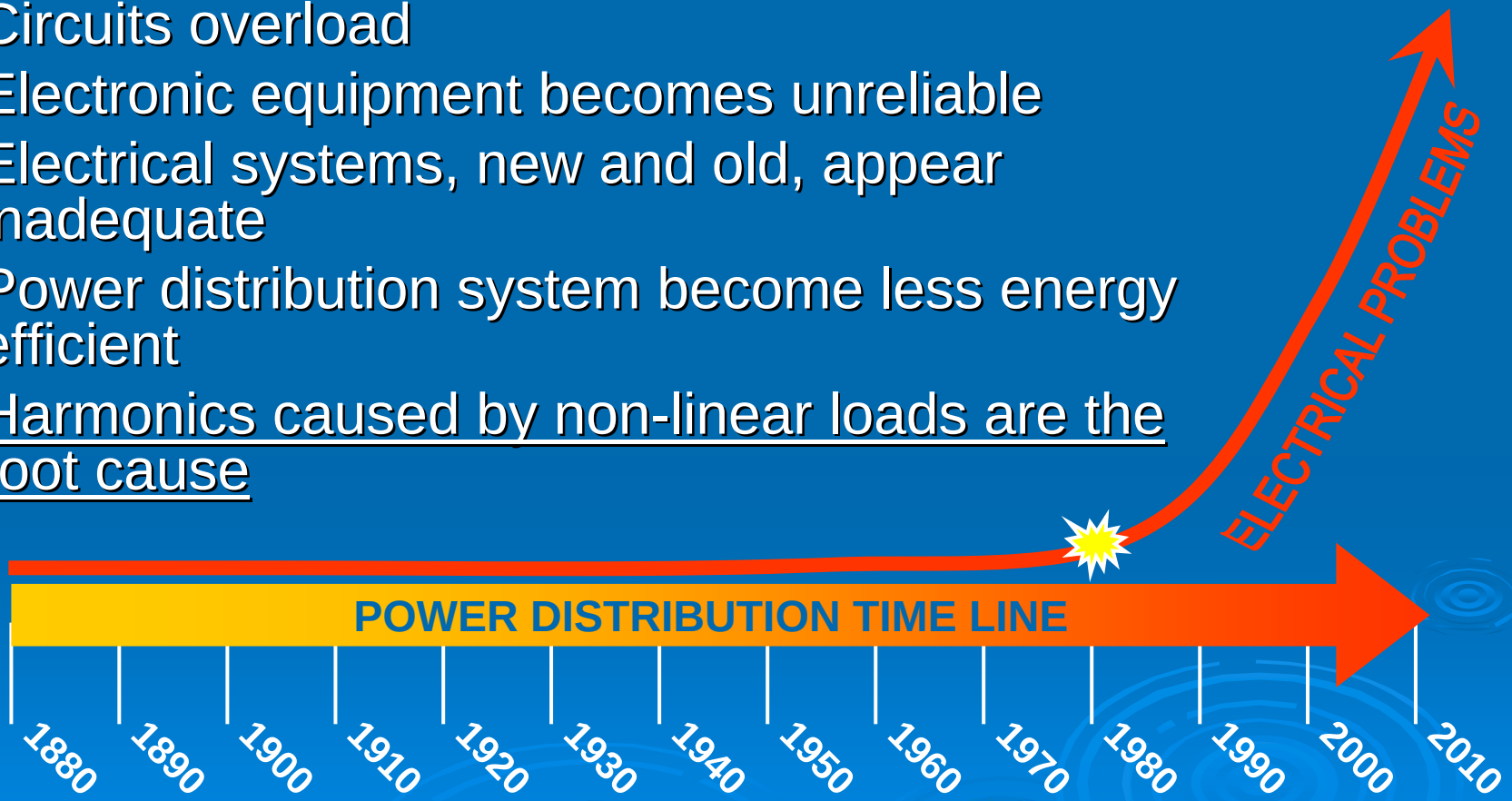
7 x 60 = 420HZ

11 x 60 = 660HZ

13 x 60 = 780HZ

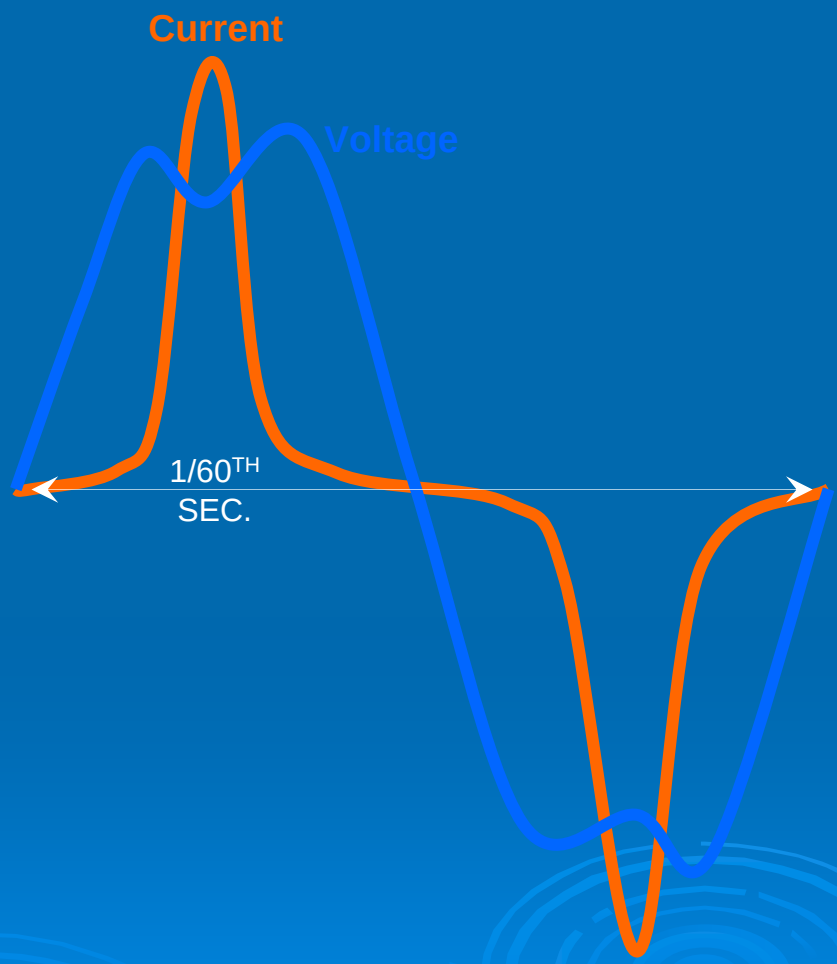
Non-Linear Loads Tax Our Facilities' Electrical Systems and Decrease Reliability

- Transformers overheat impacting life expectancy
- Circuits overload
- Electronic equipment becomes unreliable
- Electrical systems, new and old, appear inadequate
- Power distribution system become less energy efficient
- Harmonics caused by non-linear loads are the root cause

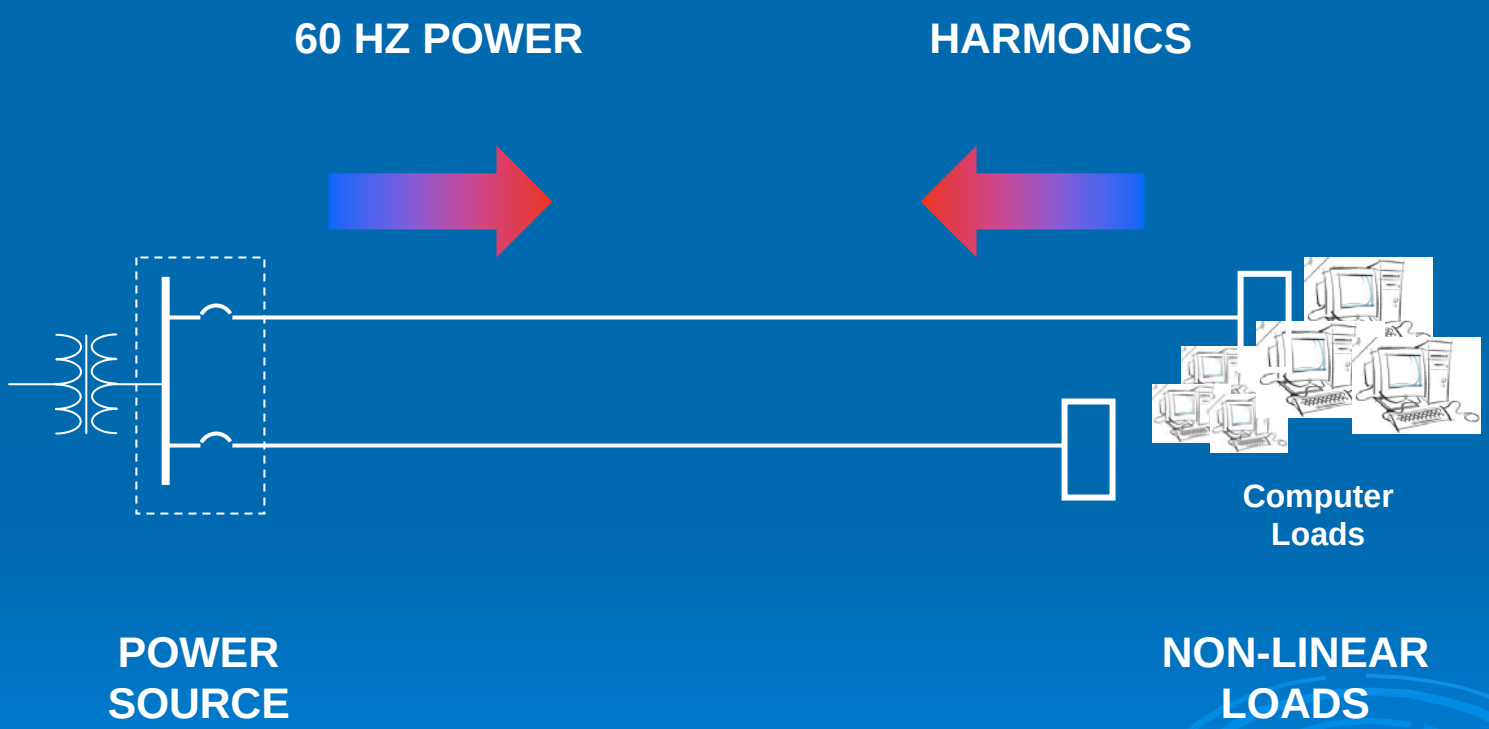


Non-Linear Loads Draw Power Unevenly

- Current is drawn in short “gulps” or pulses.
- Voltage and Current waveforms are irregular and don’t match – waveforms are said to be “DISTORTED”
- NON-LINEAR LOADS PRODUCE HARMONICS
- Harmonics cause mis-operation of equipment and WASTE ENERGY.

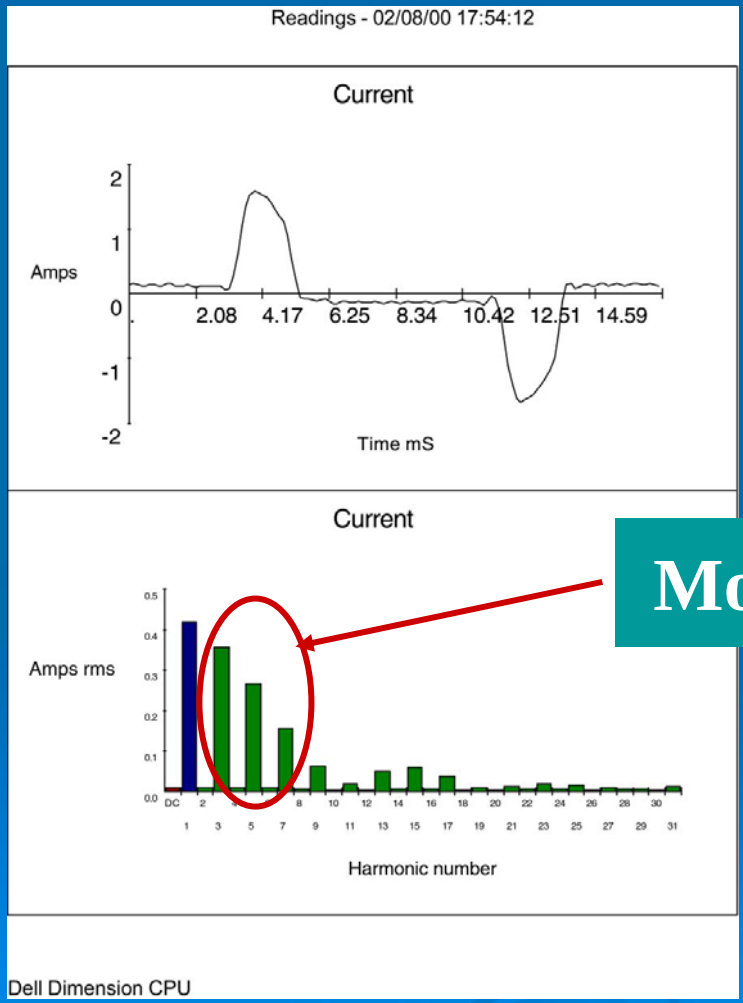


Harmonics Are Generated By the Load and Flow Upstream Toward the Source



Computers and other 120V electronics

Single-Phase Harmonic Spectrum



Mostly 3rd, 5th & 7th

Transformer Losses

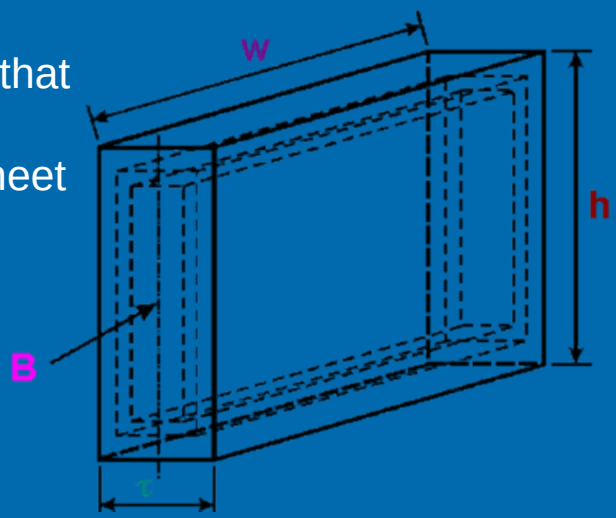
Frequency can be a killer

Eddy-current losses

The AC flux induces emfs in the core that produce eddy currents that circulate in the iron. Eddy-current losses are proportional to the frequency, the maximum flux density, the thickness of the core sheet and the resistivity of the iron (inversely).

$$P_e = \frac{Vol * \pi^2 * f^2 * \tau^2 * B^2}{6\rho}$$

$$Vol = w\,\tau\,h$$

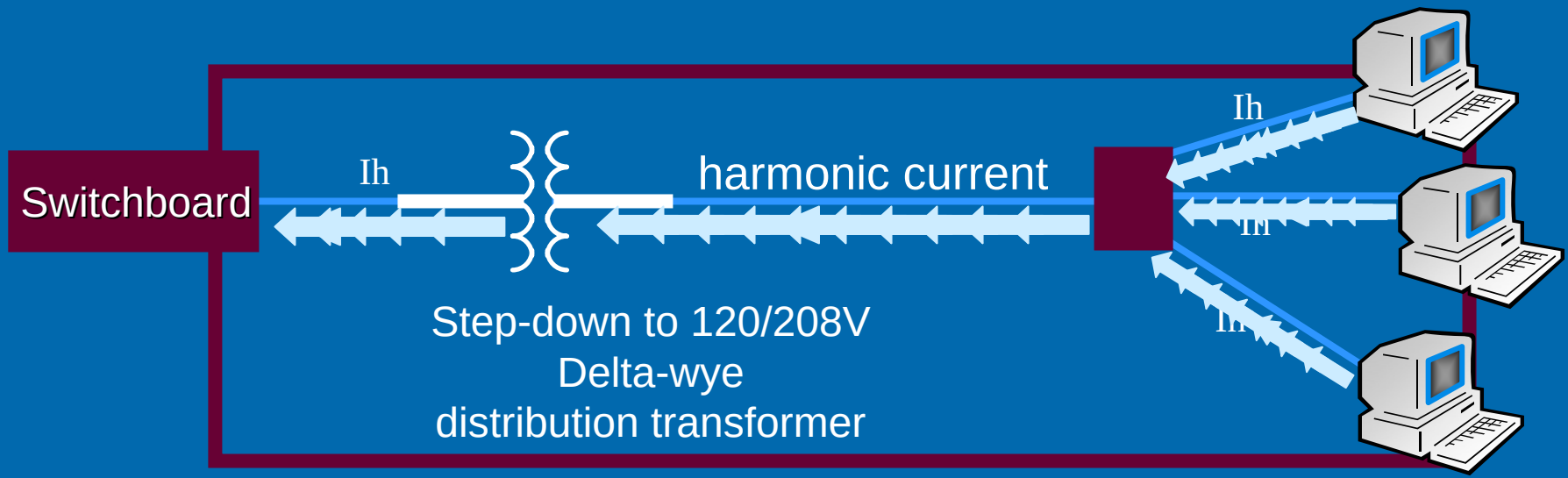


"At 100% THD, the copper loss doubled, and the eddy current loss increased by more than 17 times. Consequently, the 112-kVA transformer is overloaded by only 60 kW of computers."

IEEE Transactions on Industry Applications, Sept/Oct. '96
"Costs and Benefits of Harmonic Current Reduction for Switch-Mode Power Supplies in a Commercial Office Building"

Tom Key, PEAC
Jih-Sheng Lai, Oak Ridge National Lab, Lockheed Martin Energy Research

Interaction of Harmonic Current with System Impedance



Transformer Loss Data

Table VI

Transformer T_1 Harmonic-Related Losses and Cost Per Year

Load = 60 kW 3-phase, on 112 kVA	P_{loss} (W)	Cost/Year
Copper loss = $\Sigma\ I_h^2R$	2986	$1,308
Eddy current loss $P_{EC} = \Sigma\ I_h^2h^2$	1336	$585
Total load loss $P_{LL} = \Sigma\ I_h^2R+P_{EC}$	4322	$1,893
Base load loss = 1.05 x I^2R	1575	$690
Penalty = P_{LL} - 1.05 x I^2R	2747	$1203

Actual Total Losses **2.7 times higher**

Linear Load Losses

Non-Linear Load Loss Multiplier

- Transformers feeding non-linear loads have greater losses.
- Non-Linear Load Loss Multiplier (NLL):

$$NLL = \frac{\text{non-linear load losses}}{\text{linear load losses}}$$

- NLL can be as high as 2.7*

* IEEE Transactions on Industry Applications, Sept/Oct. '96
"Costs and Benefits of Harmonic Current Reduction for Switch-Mode Power Supplies in a Commercial Office Building"

These Harmonic current flows on the NEUTRAL may be 1.73 times larger than the supply current.

IEEE 519 is the standard used to determine maximum Harmonic distortion levels.
They are different between voltage and current.

Is Voltage Distortion Important for Connected Equipment ?

Every harmonic standard in the world says it is. Here is an excerpt from the relevant USA standard IEEE-519:

6.6 Electronic Equipment. Power electronic equipment is susceptible to misoperation caused by harmonic distortion. This equipment is often dependent upon accurate determination of voltage zero crossings or other aspects of the voltage wave shape. Harmonic distortion can result in a shifting of the voltage zero crossing or the point at which one phase-to-phase voltage becomes greater than another phase-to-phase voltage. These are both critical points for many types of electronic circuit controls, and misoperation can result from these shifts.

Other types of electronic equipment can be affected by transmission of ac supply harmonics through the equipment power supply or by magnetic coupling of harmonics into equipment components. Computers and allied equipment such as programmable controllers frequently require ac sources that have no more than a 5% harmonic voltage distortion factor, with the largest single harmonic being no more than 3% of the fundamental voltage. Higher levels of harmonics result in erratic, sometimes subtle, malfunctions of the equipment that can, in some cases, have serious consequences. Instruments can be affected similarly, giving erroneous data or otherwise performing unpredictably. Perhaps the most serious of these are malfunctions in medical instruments. Consequently, many medical instruments are provided with line-conditioned power. Less dramatic interference effects of harmonics can occasionally

Energy Star Transformers

Commercial & Industrial Transformer Program

- Started in 1998
- Adopted NEMA TP-1 Transformer Efficiency Standard
- Efficiency Target @ 35% load level
  - Example: 75kVA 3-phase, low voltage: efficiency requirement: 98.0%
- Drawbacks
  - Not UL Listed for Electronic Equipment
  - Transformers rated for Electronic Equipment are Exempt from meeting TP-1 efficiency

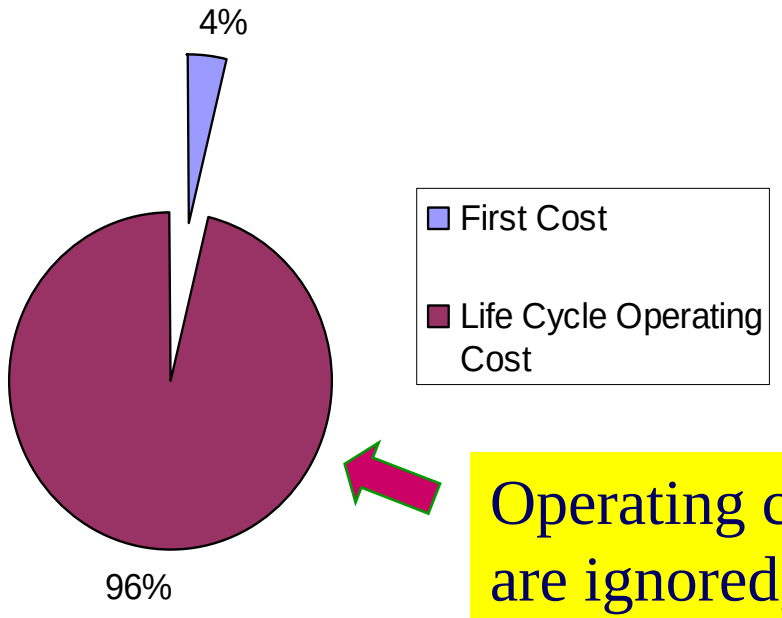
40 Transformers in a typical project today can embed a minimum of
$1,000,000
of operating cost
over 25 year life cycle of transformer.

THE EPA ESTIMATED
THAT ANNUAL

DISTRIBUTION RANSFORMER LOSSES ARE
60 - 80 BILLION KWH

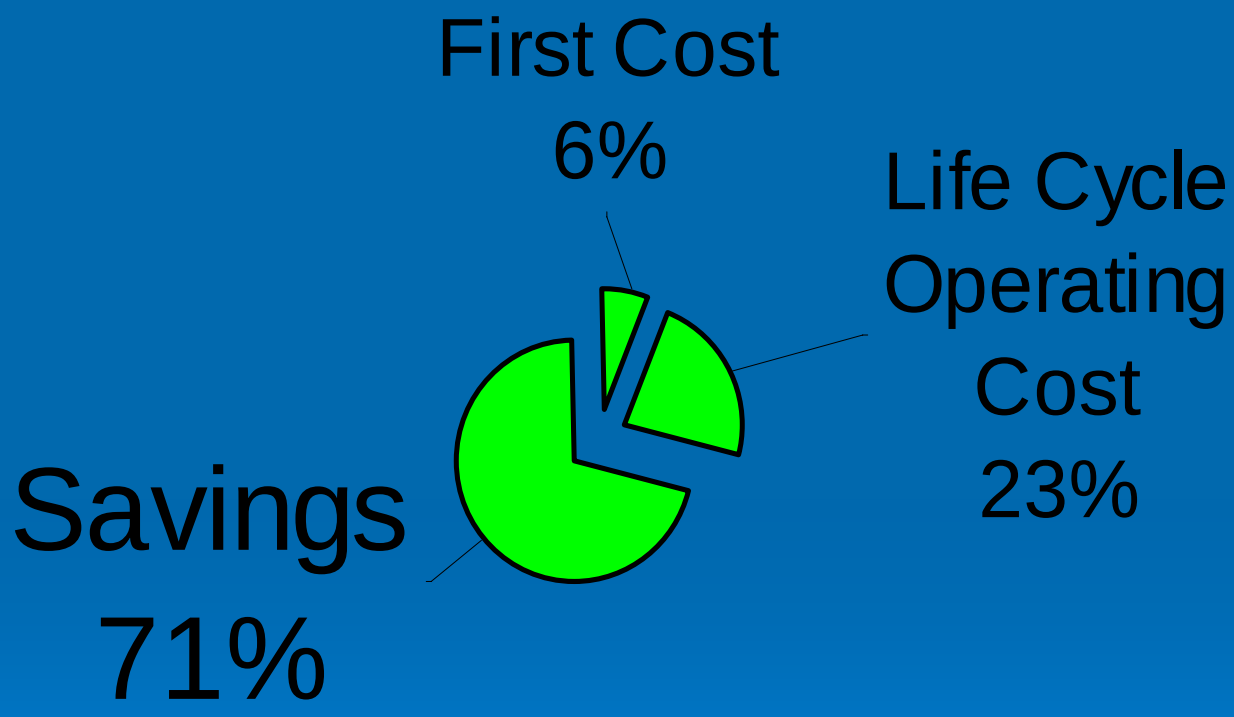
AND COSTS END USERS
$4 + BILLION EVERY YEAR.

First Cost is only 4% of Total Ownership cost

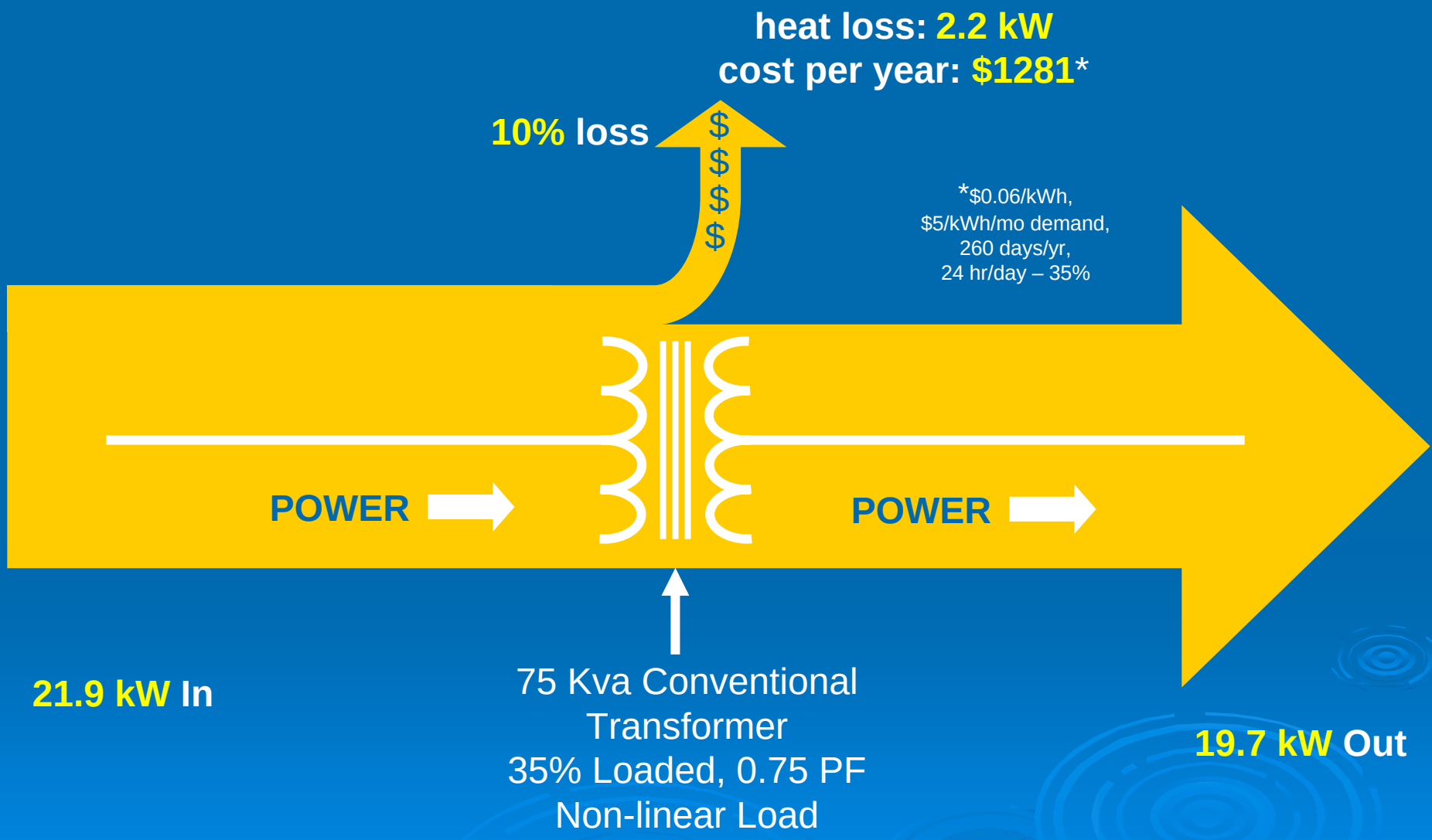


Operating cost (transformer losses) are ignored, yet offer by far the largest opportunity for savings

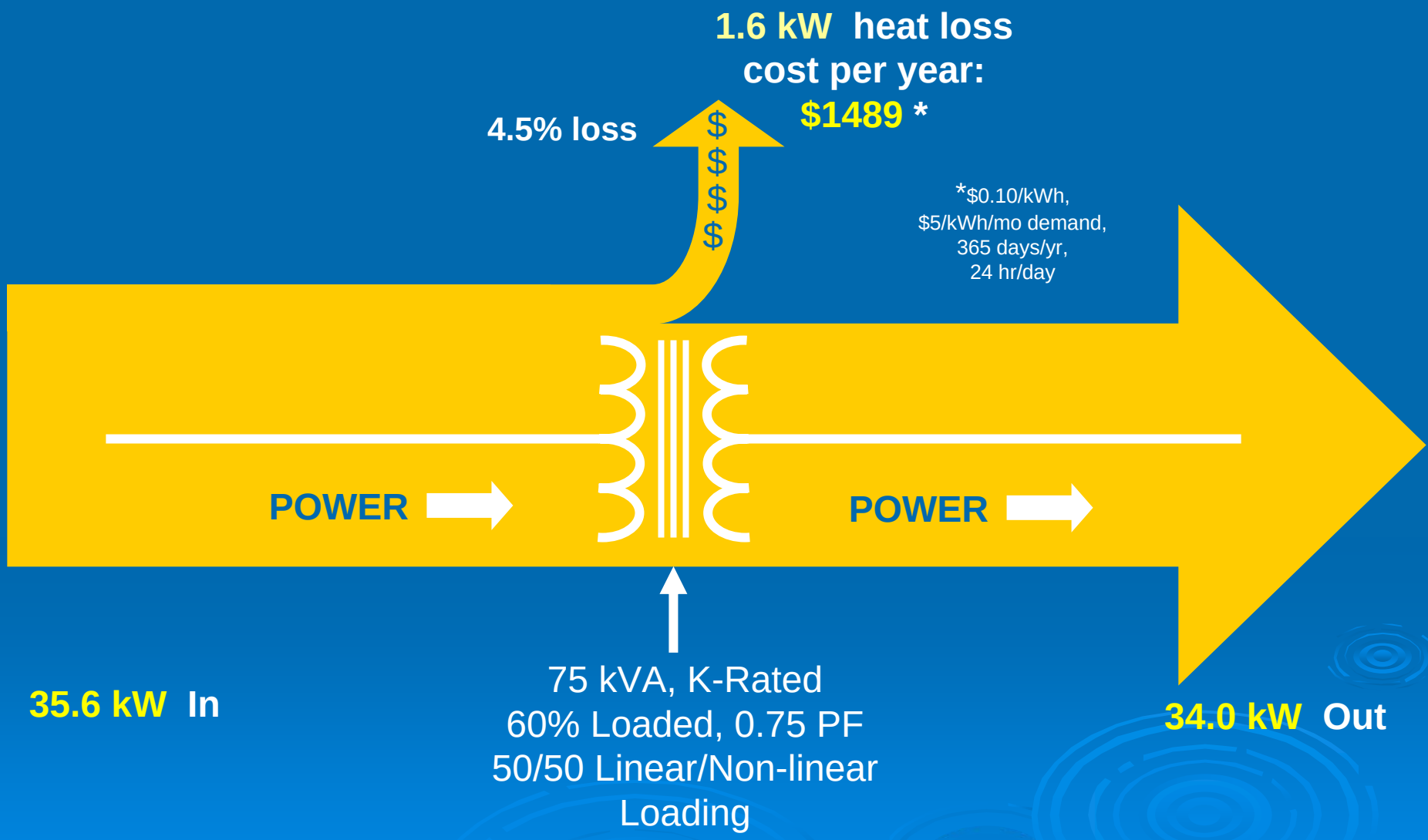
Ownership cost with High Efficiency Transformers



Typical Transformer Heat Losses

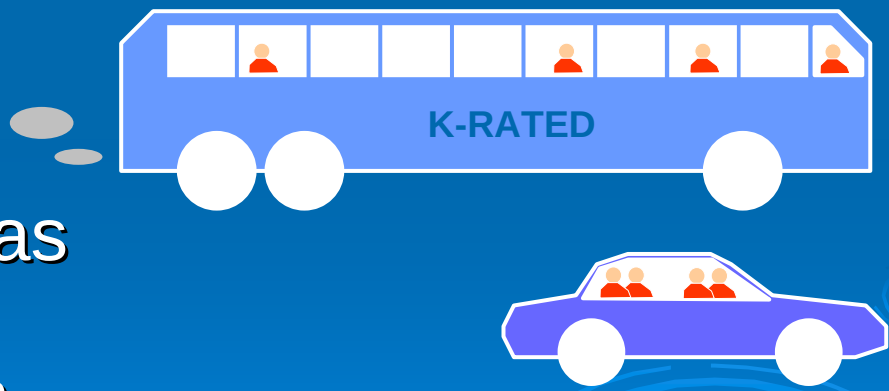


K-Rated Transformer Heat Loss



K-rated Transformer Defined:

- Overbuilt transformer designed to deliver rated (nameplate) power to non-linear loads without overheating
- K-rated transformer performs same job as conventional transformer but with less stress on itself



K-Rating = Factory Derating

The Product

- Larger core, larger conductors and/or multiple conductors to survive the extra heat
- More winding layers and shorter coil height and larger enclosure to reduce temperature rise and vent heat

The Consequences

- *harmonic currents still flow in primary and secondary*
- *create flux in core*
- *increased losses*
- *excessive voltage distortion*
- *Larger footprint*

Survival at Best – K-Rating is not the Answer

K-rated Transformers:

- Do nothing to reduce harmonics
- Are not energy efficient
  - Costly to operate
- Do not solve a long list of harmonics-related problems:
  - Overloaded neutrals
  - Overloaded circuits
  - Breaker tripping
  - Equipment reliability
  - Inadequate system capacity
  - Voltage distortion

Harmonic Correction vs. K-Rated

98% efficient (non-linear load)

52”H x 38”W x 30”D
2200 lbs

Harmonic Correcting Xfmrs’ Benefits:

- Typically 2 to 3 times more energy efficient
- One-half to one-third operating cost
- Rapid cost recovery
- Recurring energy savings over 25 year life of product
- Up to 37% less weight
- Up to 74% less volume
- Up to 62% less footprint
- Treats harmonics, improves power quality, increases reliability of critical loads

< 95% efficient (non-linear load)

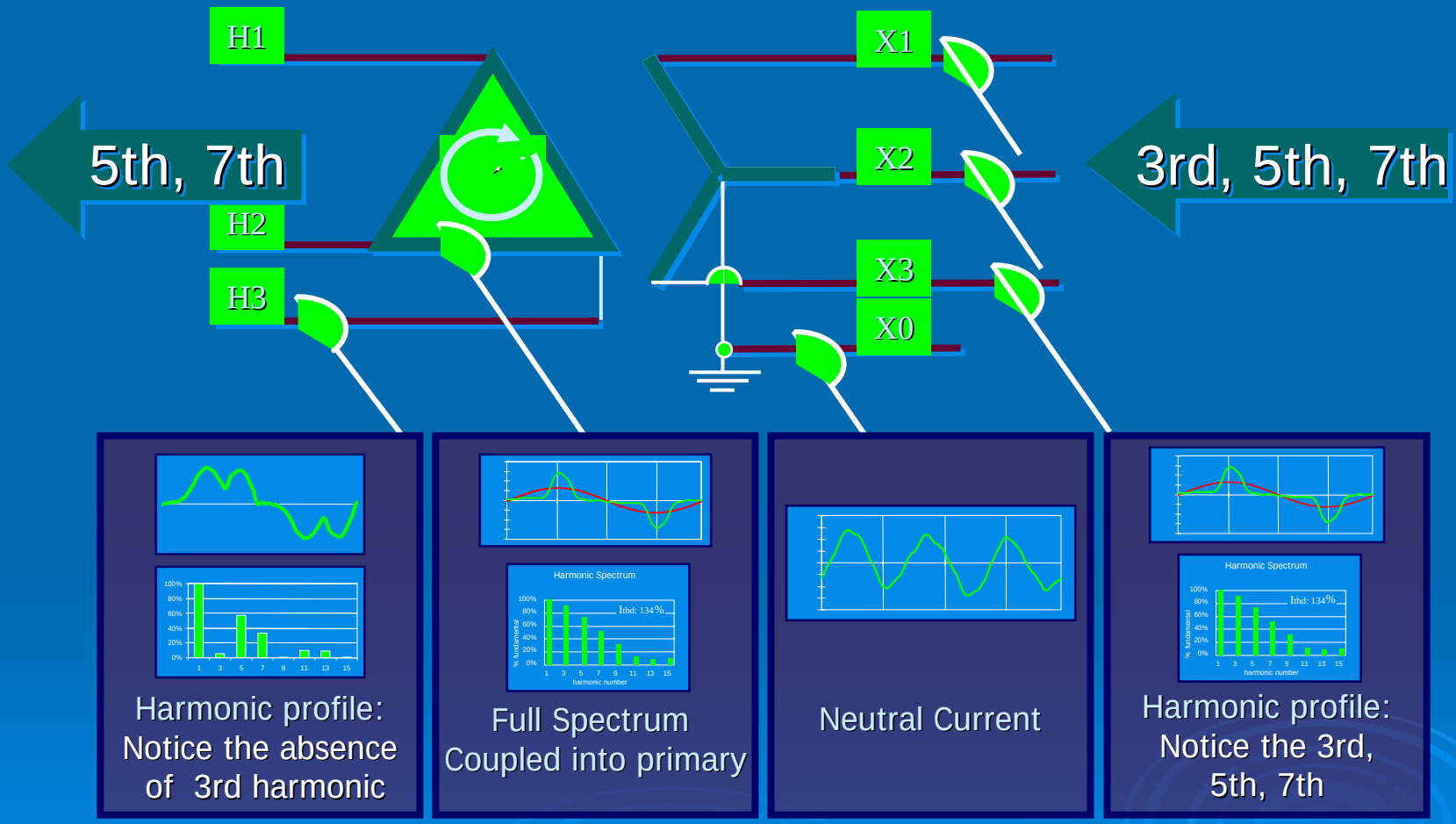
Up to 76”H x 60”W x 50”D
3480 lbs

Compare Cost of Energy Losses: Conventional K-Rated vs. Harmonic Correcting Xfmr & Including Air Conditioning Losses

	Losses (kW)	% Losses	Annual Costs
K-Rated 75 kVA	**2.2 kW***	6.1%*	$2024*
Harmonic Correction 75 kVA	**0.9 kW***	2.5%*	$877*
Savings	**1.2 kW***	_____	$1148*

* Includes 36% allowance for air conditioning losses for removing transformer's waste heat.

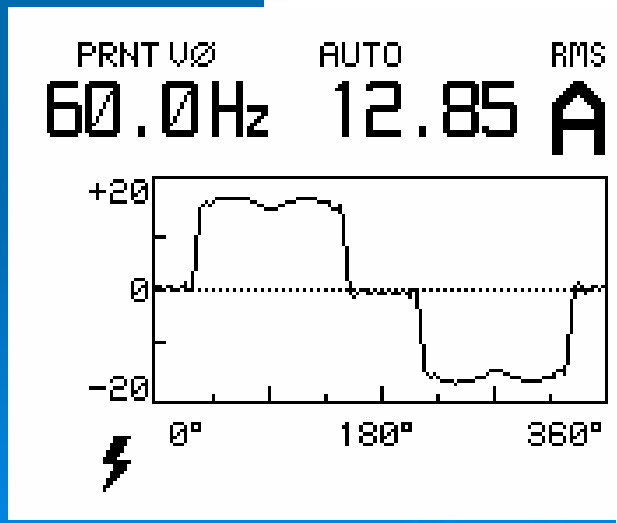
Harmonic current flow through Delta-Wye Transformer

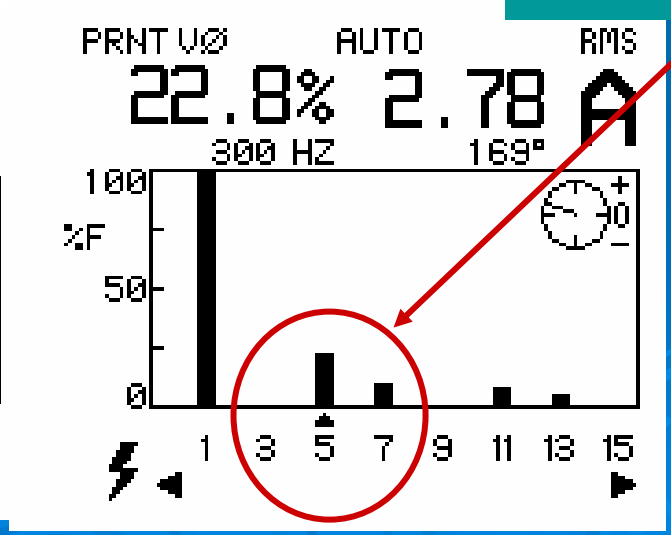


Variable Frequency Drive, rectifiers ...
3-phase Harmonic Spectrum

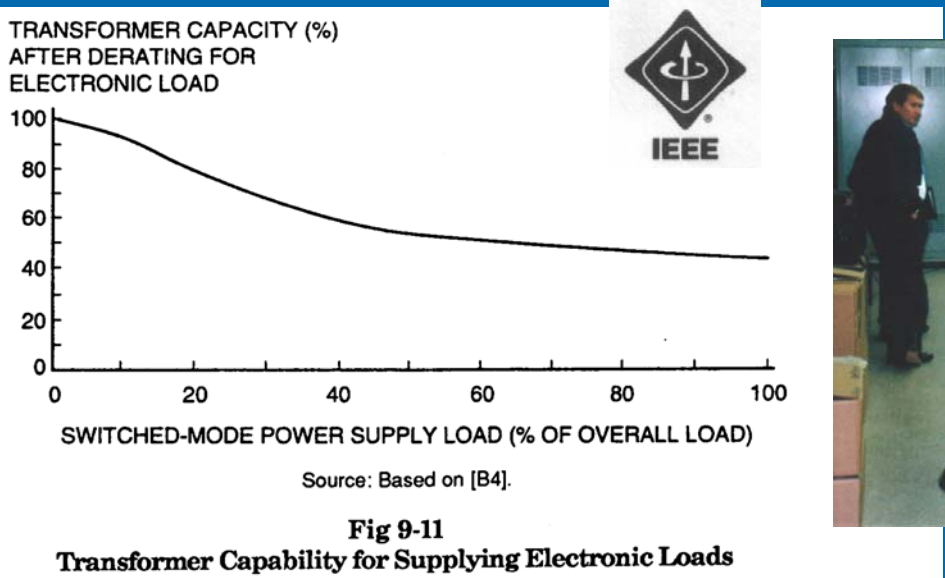
Most Drives are 6-pulse

- Mostly 5th and 7th
- No 3rd





Transformer Derating
Per IEEE-1100 "The Emerald Book"

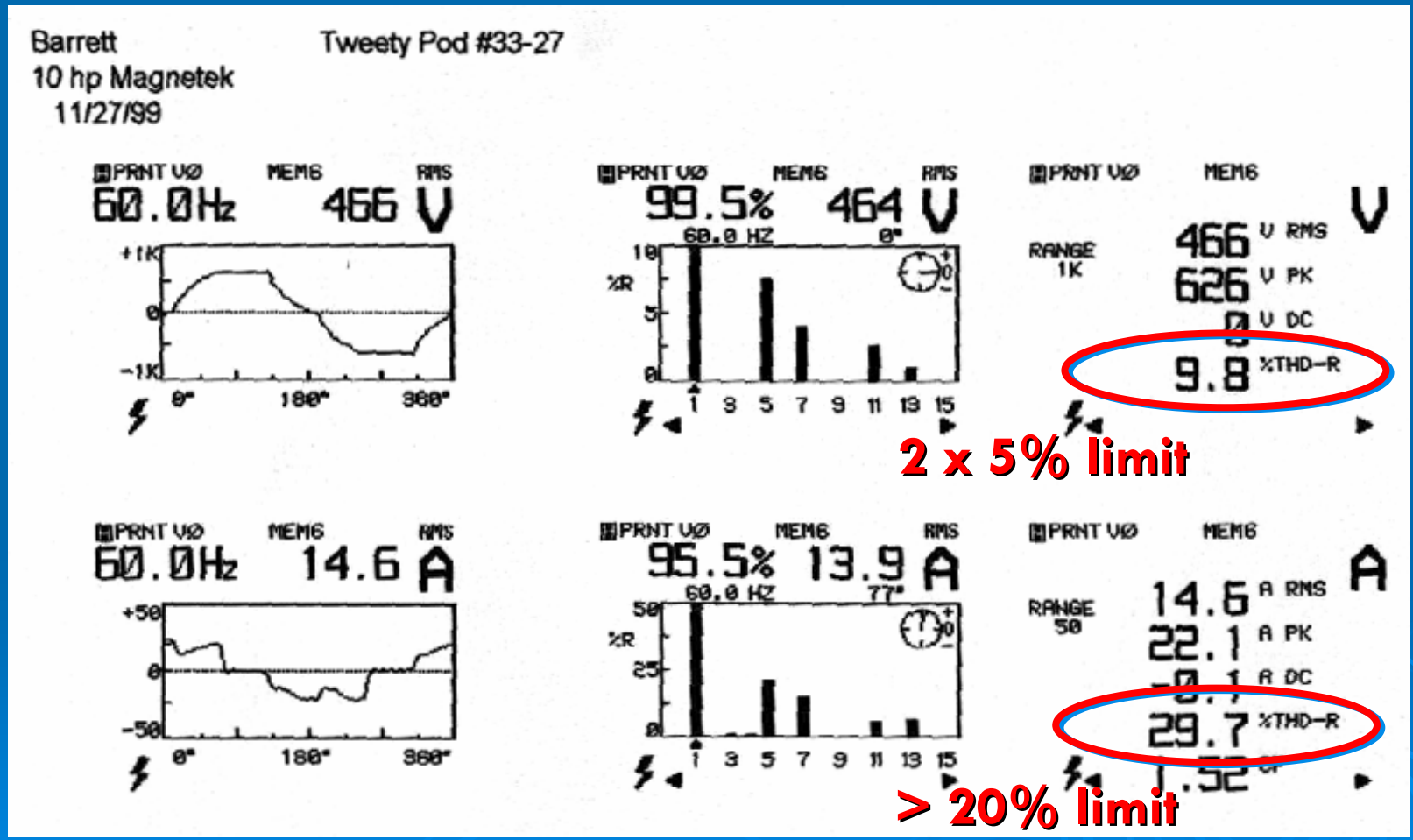


Source: Based on [B4].

Fig 9-11
Transformer Capability for Supplying Electronic Loads

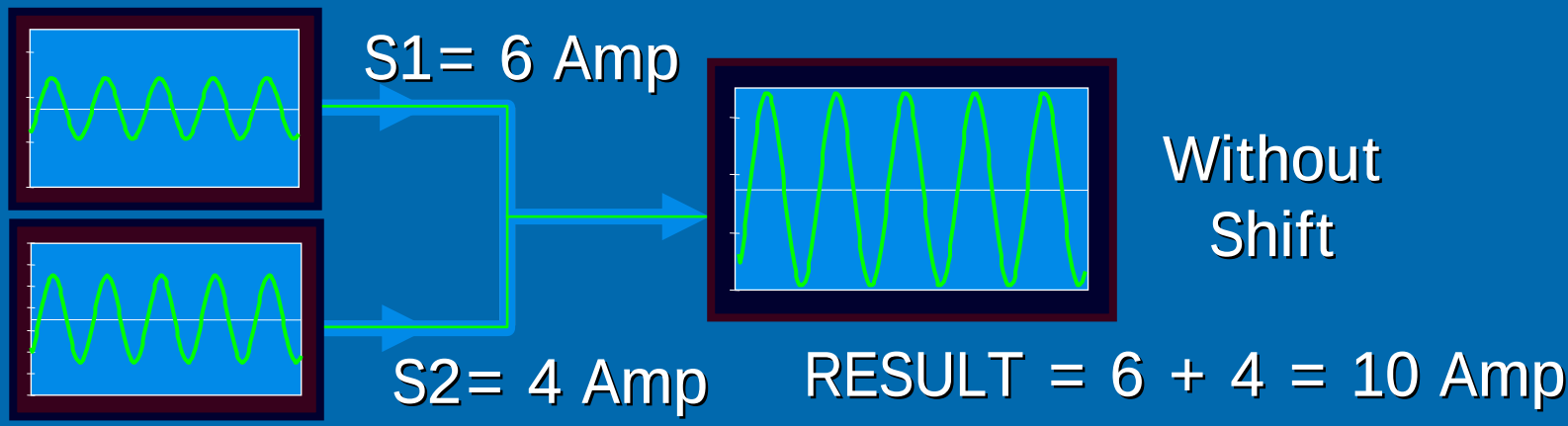
IMPORTANT: ***50-60% Lost capacity*** *from harmonic heating even if only half the load is nonlinear*

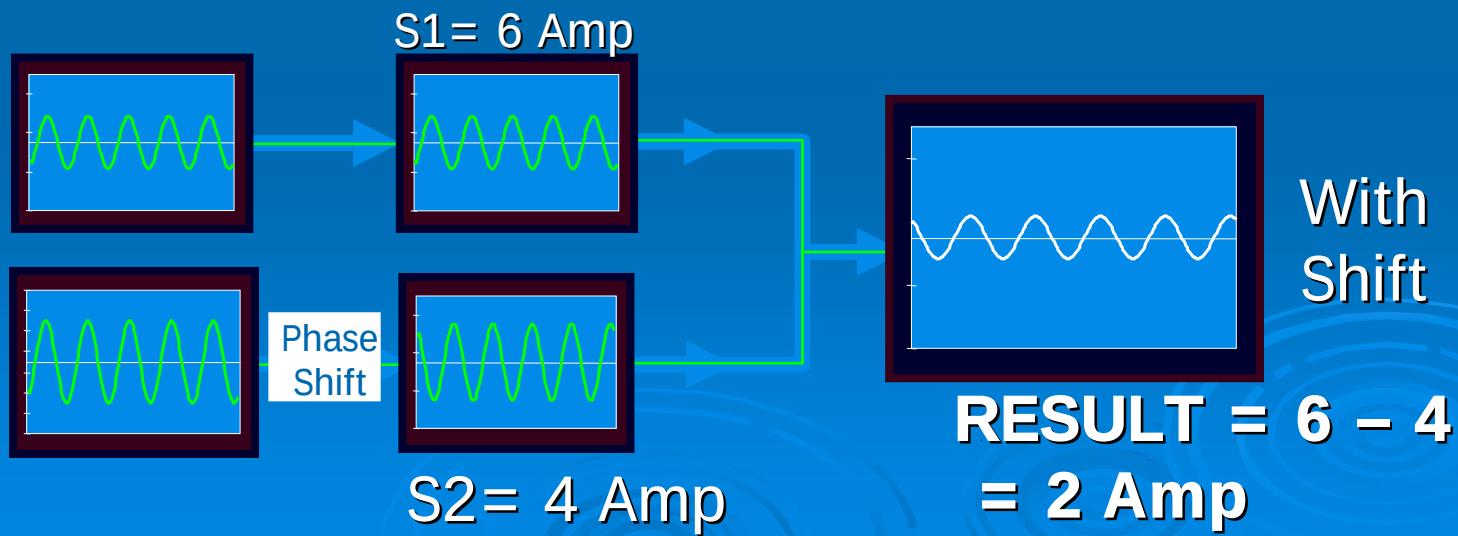
VFDs and resulting System Voltage



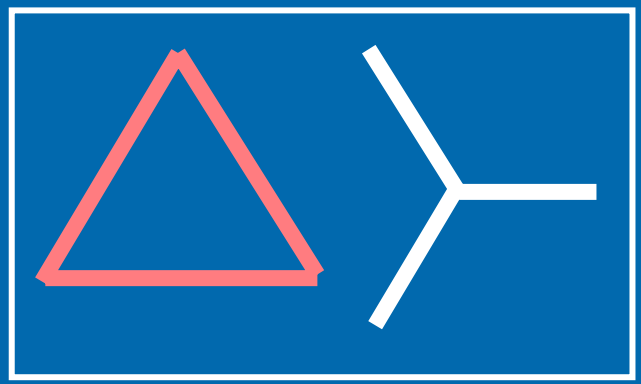
HOW ARE THEY DIFFERENT ?

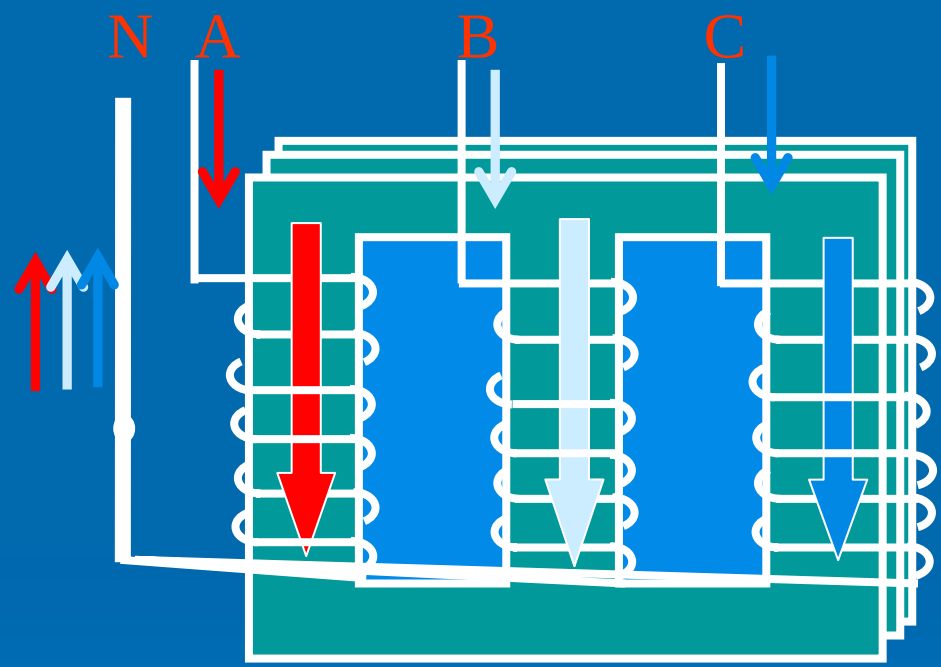
Phase Shifting – Cancel 5 th & 7 th Harmonic Currents





Delta-Wye Transformer
all harmonic currents flow in windings

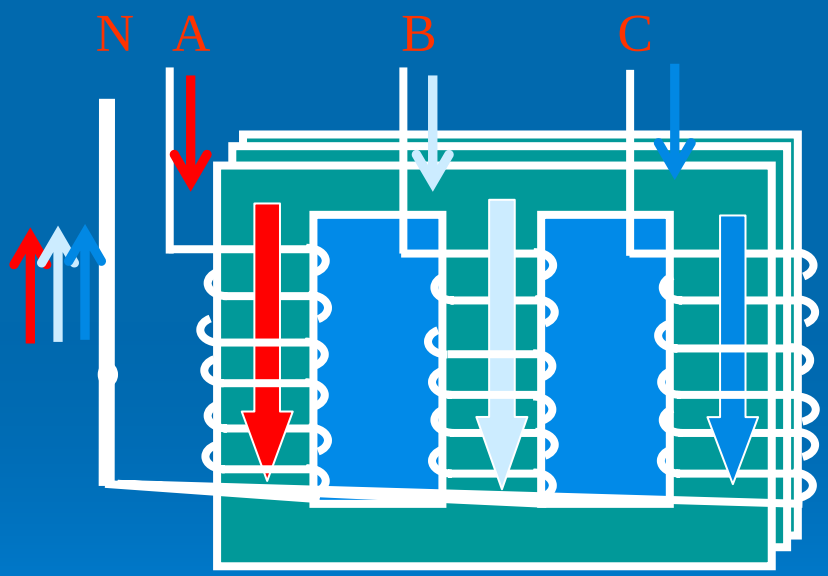




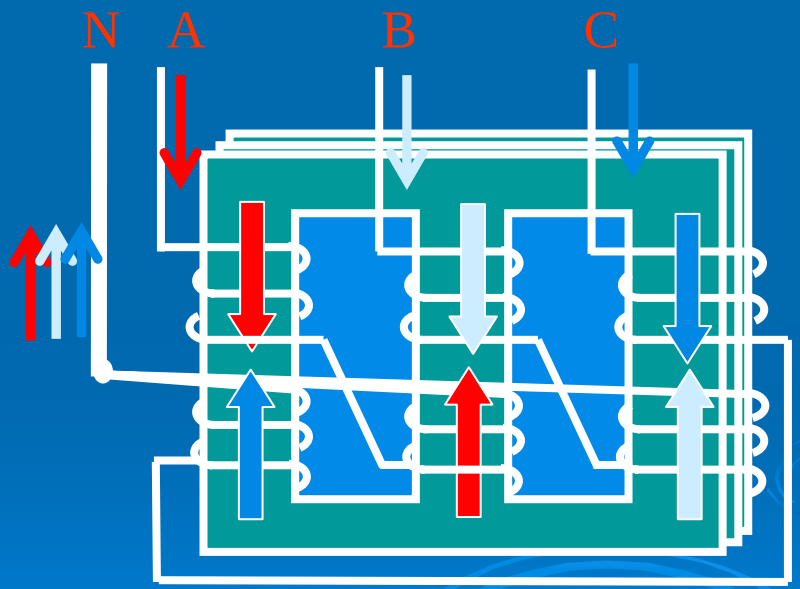
- Harmonic current in secondary wye induces flux in core
- Flux induces current in delta primary
- One full coil per leg means full harmonic coupling
- Therefore Heat and Voltage THD are substantial

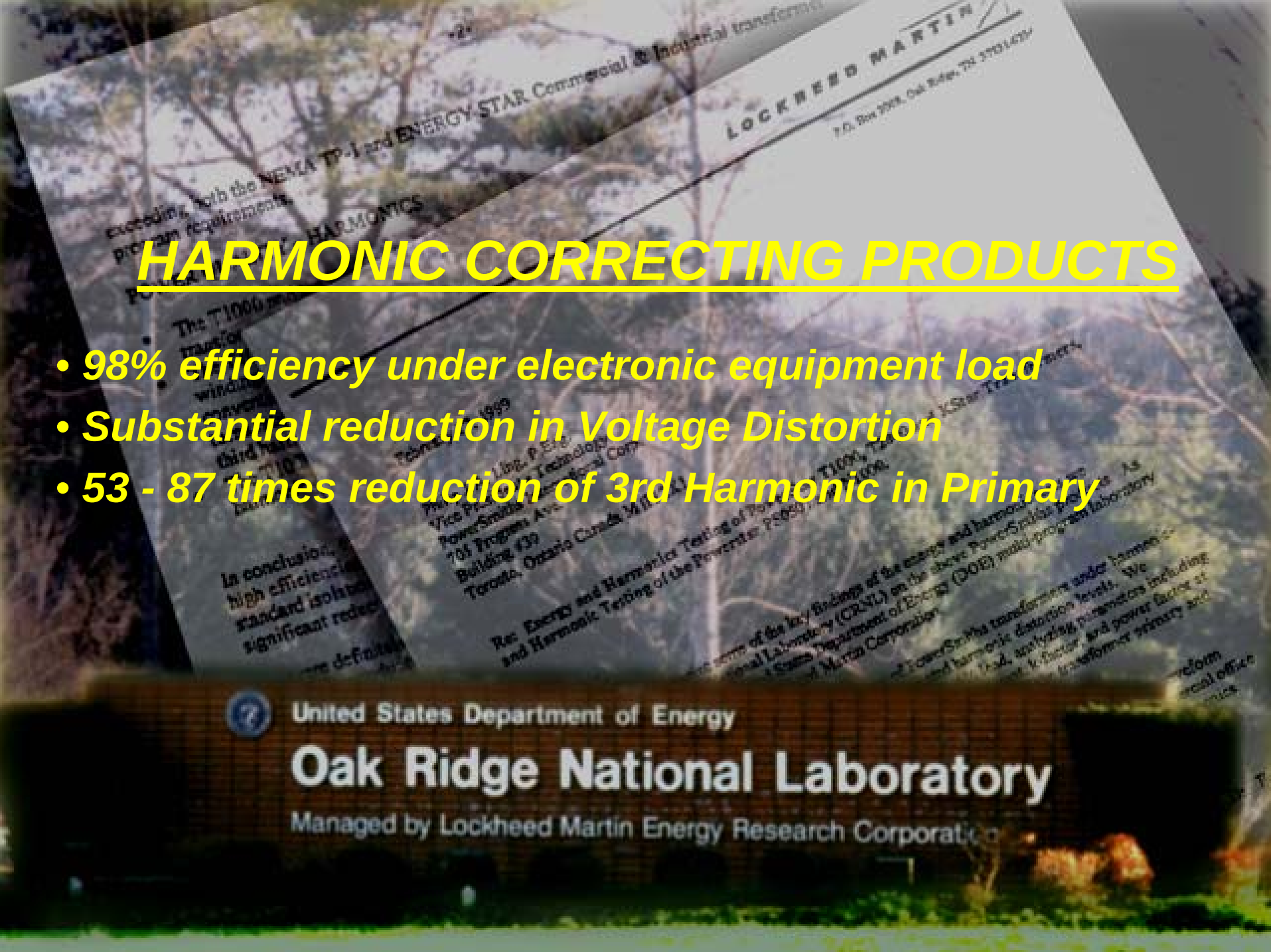
Harmonic Correcting Coils are Built Different

Standard Wye Secondary



Harmonic Secondary



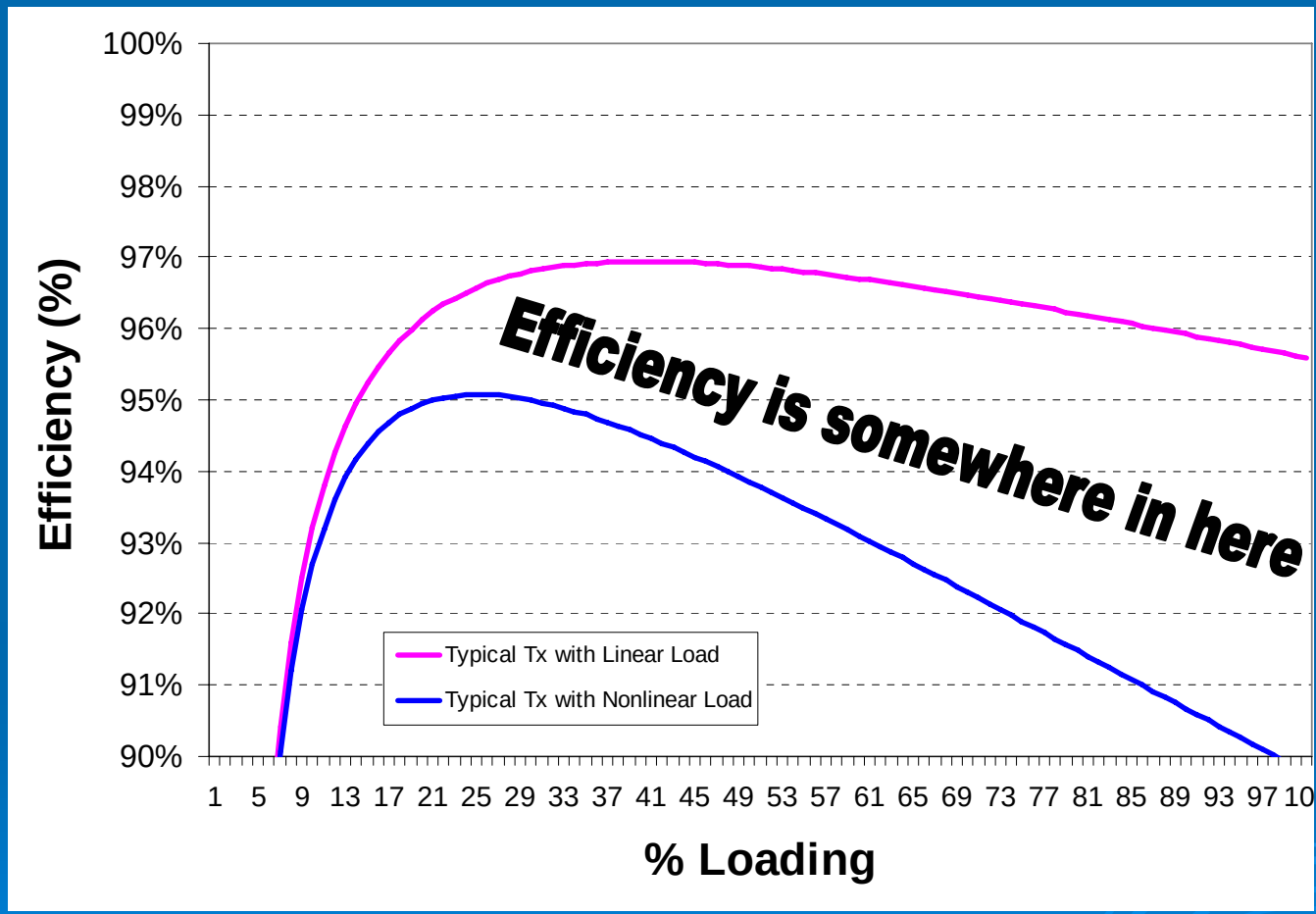


HARMONIC CORRECTING PRODUCTS

- *98% efficiency under electronic equipment load*
- *Substantial reduction in Voltage Distortion*
- *53 - 87 times reduction of 3rd Harmonic in Primary*

Energy Deficiency

Typical 112.5kVA Nonlinear UL listed transformer



Significant variation in efficiency over load range & concentration of electronic equipment

On the Benefits of Harmonic treatment

Bill Guy, Senior Electrical Engineer, Intel Corporation

After installation of ~$20,000 of Harmonic Correcting products

"…after a year of operation on the new system, the lab owner indicates the following improvements:

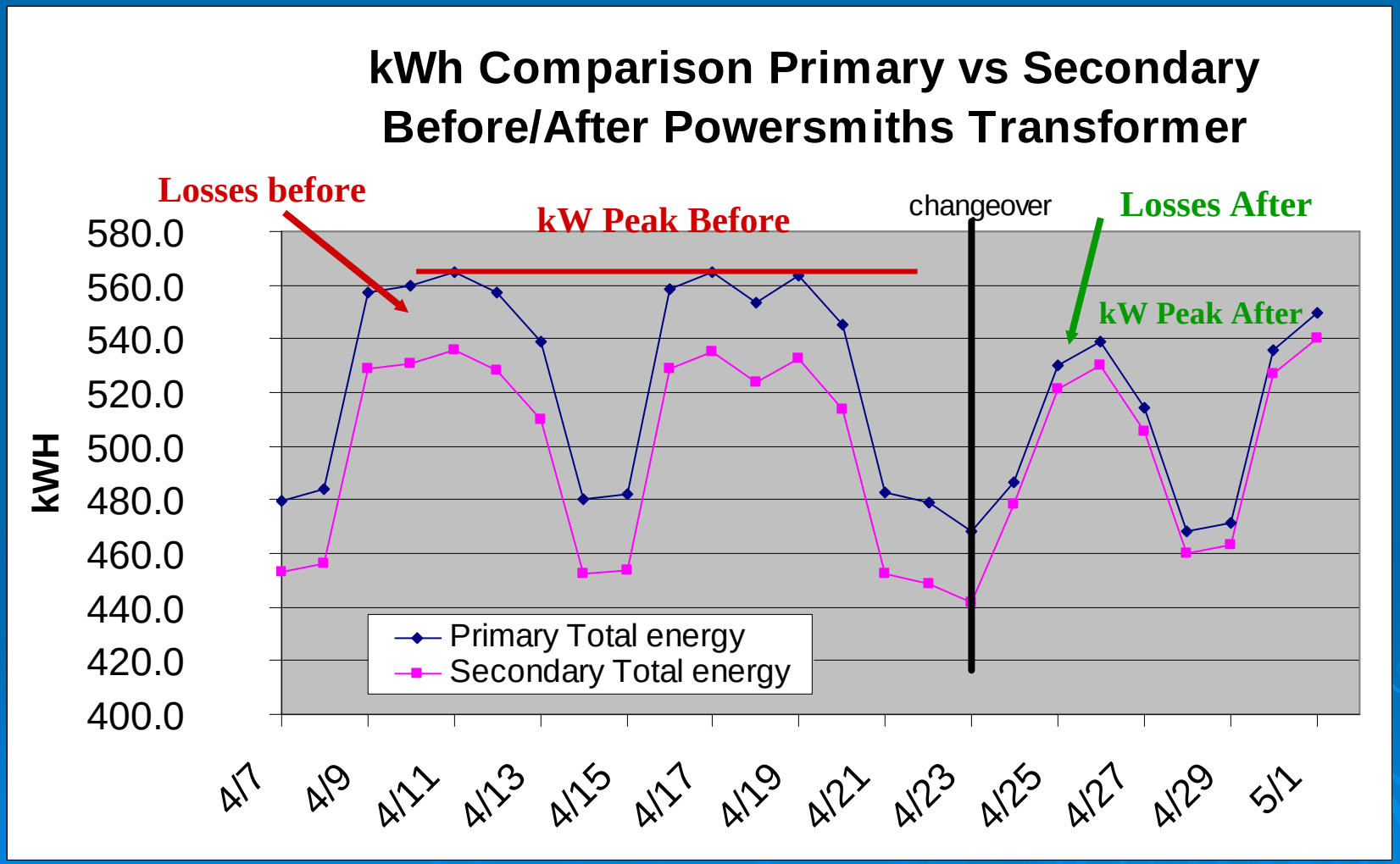
Problem Area:	Before Correction:	After Correction:
Hard Drive failures	80	1
Power Supply failures	10	0
Mother Board failures	20	0

*****82% reduction in Engineering time looking for "Mysterious Lock-ups"

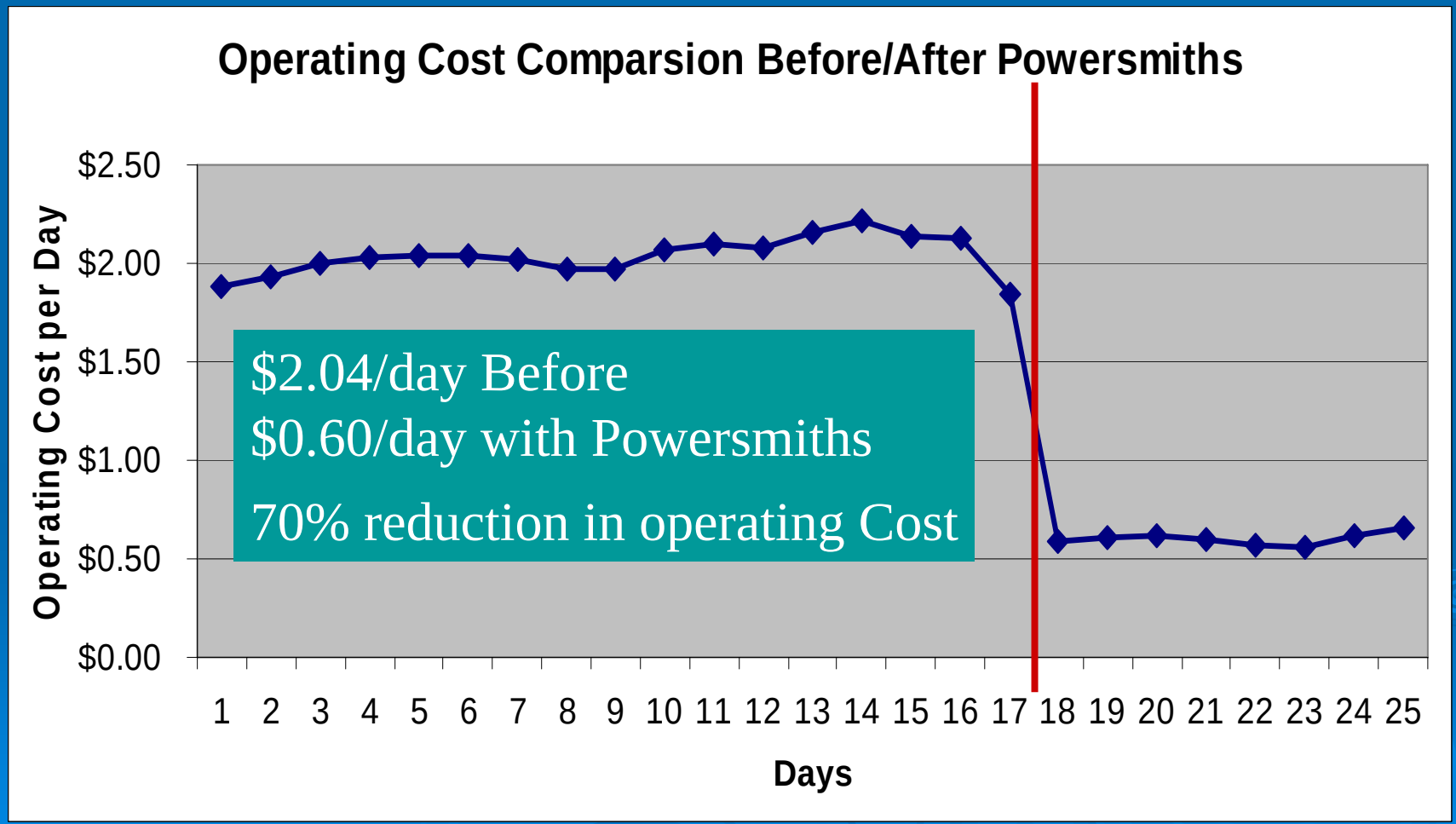
This conservatively accounts for an annual savings to this lab of over $200,000 by adding up the hardware losses and the 1.25 years of engineering time per year in researching the 'mysterious lock-ups'. Please note that this is a documented savings in one (1) lab! And does not include any energy savings"

Subject: IEEE-IAS HARMONICS DIANOSIS AND REMEDY; CASE STUDIES
Published in: THE BIAS
THE BULLETION FOR INDUSTRY APPLICATIONS SOCIETY
IEEE OREGON SECTION

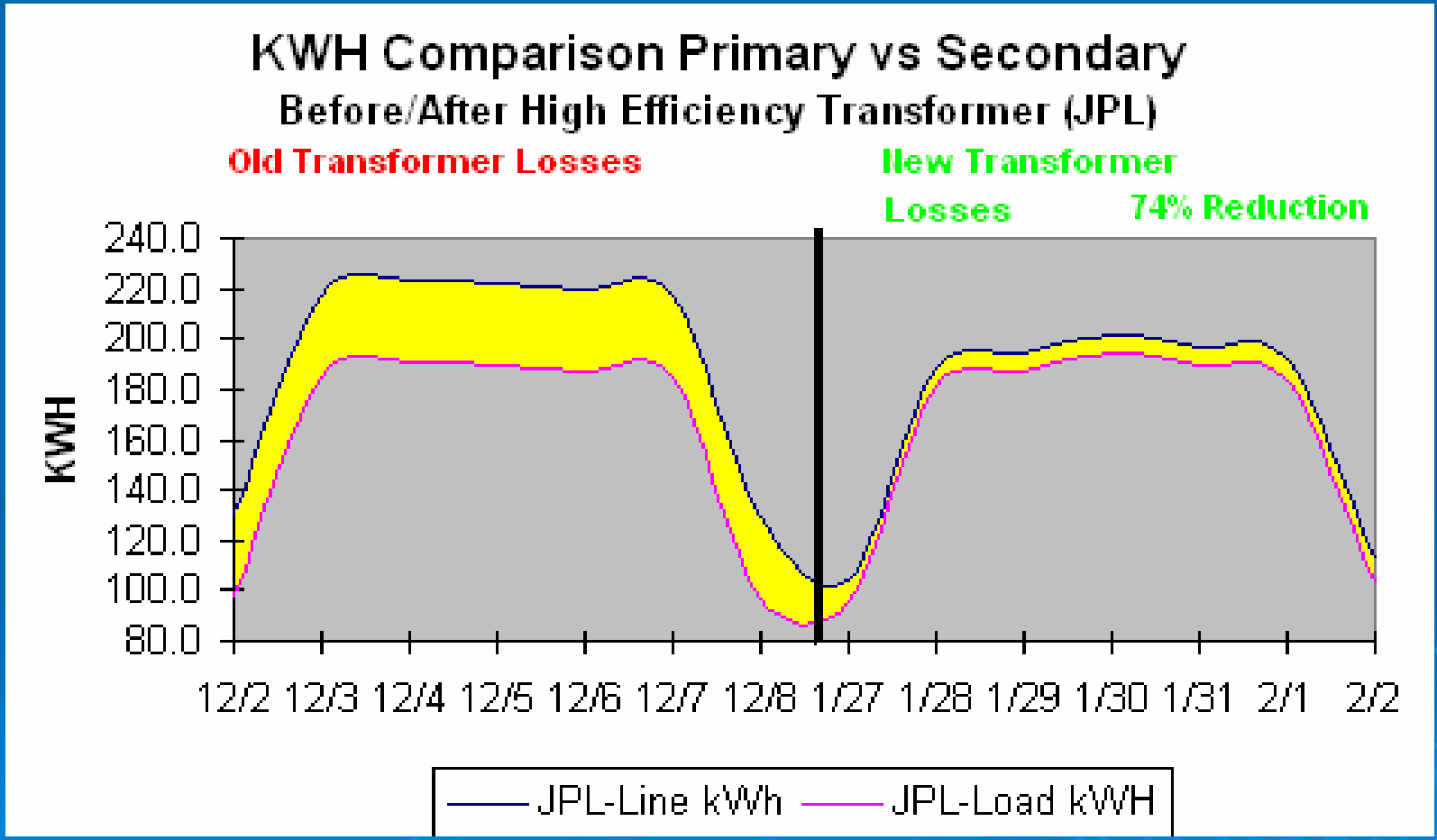
Seattle Case Study: Peak and Consumption Savings / Harmonic Correction



Seattle Case Study
Operating Cost Savings
with Harmonic Correction



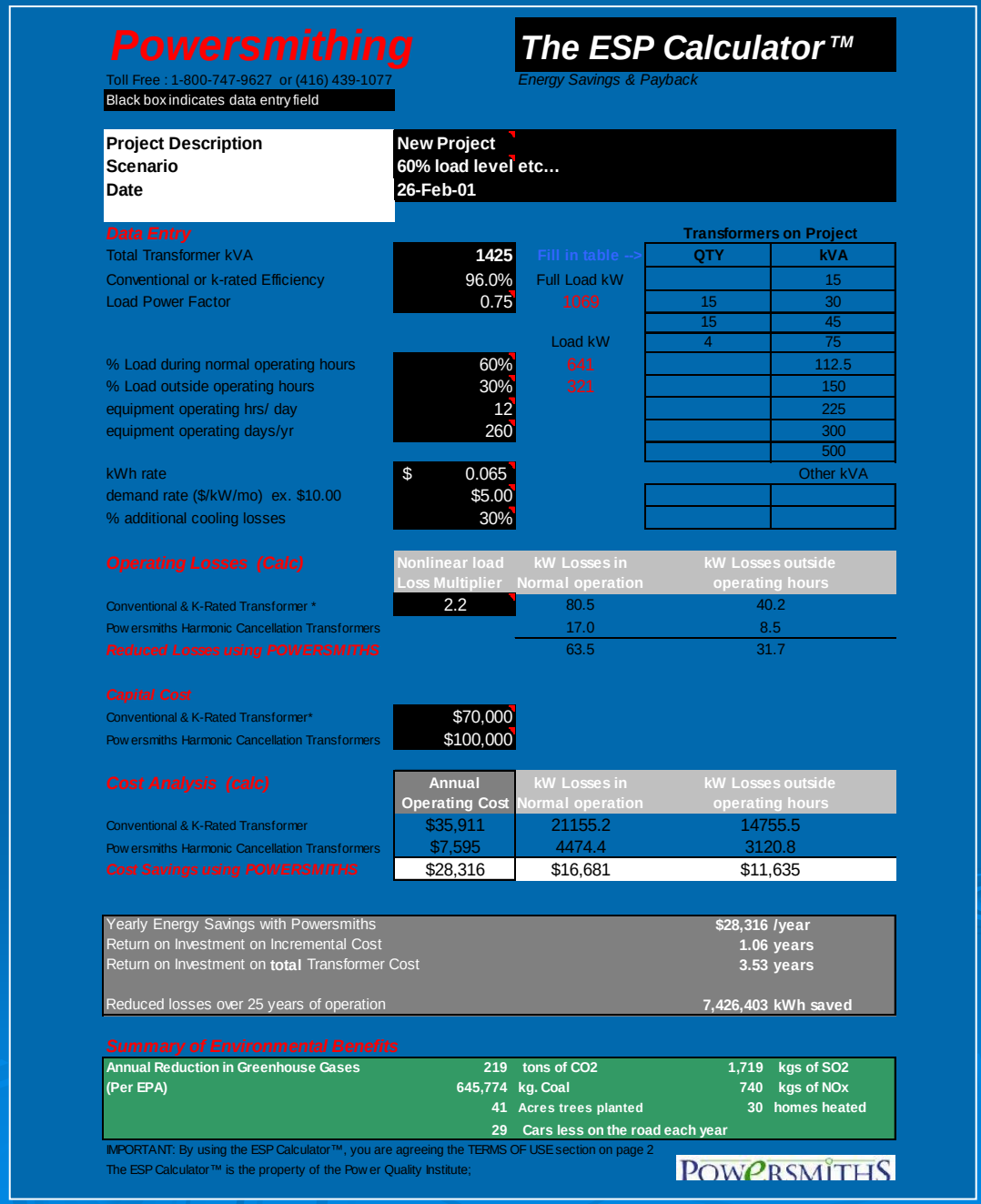
University of Texas Case Study by Utility



Powersmiths

Energy Savings & Payback Calculator

- Excel Spreadsheet
- Easy to use tool for lifecycle costing
- Calculates return on investment and Environmental Benefits



Powersmithing

Toll Free : 1-800-747-9627 or (416) 439-1077

Black box indicates data entry field

The ESP Calculator™

Energy Savings & Payback

Project Description	New Project
Scenario	60% load level etc...
Date	26-Feb-01

Data Entry

Total Transformer kVA	1425	Fill in table -->	
Conventional or k-rated Efficiency	96.0%	Full Load kW	
Load Power Factor	0.75	1069	
		Load kW	
% Load during normal operating hours	60%	641	
% Load outside operating hours	30%	321	
equipment operating hrs/ day	12		
equipment operating days/yr	260		
kWh rate	$ 0.065		
demand rate ($/kW/mo) ex. $10.00	$5.00		
% additional cooling losses	30%		

Transformers on Project

QTY	kVA
	15
15	30
15	45
4	75
	112.5
	150
	225
	300
	500
	Other kVA

Operating Losses (Calc)

	Nonlinear load Loss Multiplier	kW Losses in Normal operation	kW Losses outside operating hours
Conventional & K-Rated Transformer *	2.2	80.5	40.2
Powersmiths Harmonic Cancellation Transformers		17.0	8.5
Reduced Losses using POWERSMITHS		63.5	31.7

Capital Cost

Conventional & K-Rated Transformer*	$70,000
Powersmiths Harmonic Cancellation Transformers	$100,000

Cost Analysis (calc)

	Annual Operating Cost	kW Losses in Normal operation	kW Losses outside operating hours
Conventional & K-Rated Transformer	$35,911	21155.2	14755.5
Powersmiths Harmonic Cancellation Transformers	$7,595	4474.4	3120.8
Cost Savings using POWERSMITHS	$28,316	$16,681	$11,635

Yearly Energy Savings with Powersmiths	$28,316 /year
Return on Investment on Incremental Cost	1.06 years
Return on Investment on **total** Transformer Cost	3.53 years
Reduced losses over 25 years of operation	7,426,403 kWh saved

Summary of Environmental Benefits

Annual Reduction in Greenhouse Gases	219	tons of CO2	1,719	kgs of SO2
(Per EPA)	645,774	kg. Coal	740	kgs of NOx
	41	Acres trees planted	30	homes heated
	29	Cars less on the road each year		

IMPORTANT: By using the ESP Calculator™, you are agreeing the TERMS OF USE section on page 2

The ESP Calculator™ is the property of the Power Quality Institute;

POWERSMITHS

THANK YOU !